Control of electrical networks: robustness and power sharing

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7 Conclusions

In this thesis, we developed a method for analysis of power systems using strict Lyapunov functions. Using such functions, it is possible to prove that the dynamics of an AC power network, modelled using the swing equations in closed loop with various controllers, converges exponentially to a stable operating point under modest assumptions.

This result allowed us to additionally infer robustness of the closed loop system to various external disturbances. Specifically, the system is locally asymptotically stable even under intermittent removal of the communication network, provided an additional assumption on persistency of excitation (Assumption 2.2) is met. Additionally, we were able to show input-to-state stability with restrictions, with respect to additive disturbances in power measurements, controller output and controller communication.

It is our hope that with these robustness certificates, consensus-like controllers will be considered by network operators as a viable and safe alternative to centralised regulation. This would hopefully lead to a more flexible power network, where power users and power providers can adapt quickly to changing supply and demand, and grey power can be gradually retired from its role as necessary source of stability.

In the second part, we developed power consensus controllers for the DC power network. Like the DAI controller covered in Part I, these require the power sources to send each other instantaneous measurements of a physical quantity, but in turn offer an attractive power sharing property. In modern power grids, where not all sources and loads are flexible, control algorithms like these can be used to minimize pollution and waste, use clean sources of energy when available, and cheap ones when possible. Additionally, and again similarly to the DAI controller, its use can be extended to include flexible loads ('smart homes' etcetera) in the balancing act if desired, by modelling them as a combination of a load and a power source, further allowing society to use green power efficiently and cheaply.

7.1 RESEARCH SUGGESTIONS

The results discussed in this thesis are by no means exhaustive, and we believe they should serve as a starting point for various new developments. In the following, we suggest a few possible extensions.

7.1.1 ROBUSTNESS OF THE DAI CONTROLLED SWING EQUATIONS

Having seen that the DAI controlled swing equations are robust to DoS and to additive disturbances, one wonders if other kinds of disruptions are possible, and if so, to what extent the closed-loop power system is robust to them. Examples include

- more flexible and refined models of DoS. The current model, for example, does not allow a DoS regime in which the network is never fully connected, but each node is still connected to each other node 'most of the time' (Senejohnny et al., 2017). Various other models of partial connectivity exist, and merit an investigation;
- communication delays. In this work, the measurement–communication –calculation–actuation loop is modelled as being instantaneous. It is not difficult to see that this assumption might be unrealistic, and robustness to delays in communication, and possibly reordering of messages, is very interesting.

7.1.2 ISS OF OTHER SWING-LIKE DYNAMICS

Throughout part I, we have used strict Lyapunov functions to prove ISS and related properties for the swing equations, as used in power networks. It is likely that the same techniques will allow for similar results to be developed in other ODEs with similar nonlinearities, e.g.

$$\begin{aligned}\dot{x}_1 &= x_2 \\ \dot{x}_2 &= -x_2 - \nabla U(x_1).\end{aligned} \tag{7.1}$$

7.1.3 INCLUSION OF MORE KINDS OF LOADS WITH RL LINES

Constant power loads are not included in Chapter 6. It would be interesting to include them. Moreover, not all loads are in some way constant. For broader applicability, it would be valuable to see if consensus controllers are able to work with noisy or fluctuating loads.

7.1.4 INCLUSION OF INFLEXIBLE SOURCES IN THE DC GRID

Not all power sources can offer flexibility, and some of them (such as solar power) would perhaps be better modelled as a 'negative' load. As in this work, the load nodes are assumed to be actual loads, an extension that allows for inflexible sources (and perhaps flexible loads) would make the controller more broadly applicable.